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his absence, I hand to you, Mr. Secretary, for transmission to Dr. HILL, this medal, the highest honor this Society can possibly confer upon an astronomer, and with it I ask you to send the greetings and best wishes of the Astronomical Society of the Pacific, and that we trust the evening of his life may be a long and happy one.

March 27, 1908.

THE LAWS OF COSMICAL EVOLUTION AND THE
EXTENSION OF THE SOLAR SYSTEM
BEYOND NEPTUNE.

By T. J. J. SEE.

(Abstract of address delivered January 30, 1909.)

It has long been considered somewhat of a reproach to astronomy that the processes of cosmogony have remained so obscure that definite laws could not be established regarding even the mode of formation of the solar system, while still less was known about the laws for the development of other systems in space. In view of the great progress of the physical sciences since the time of LAPLACE, one is compelled to admit that this criticism of the oldest and most exact of the physical sciences is not wholly unjust and without a certain foundation. Not only has the failure of researches in cosmogony affected astronomy adversely, but it has also narrowed the field of effort in several of the related sciences. This should not, however, occasion surprise among those who study the history of the physical sciences. For as cosmogony depends on the other sciences for its fundamental data, any circumstance which has affected them adversely would also retard the development of cosmogony itself, and *vice versa*.

In addition to the natural difficulties inherent in the development of a complex and dependent science like cosmogony, another has arisen from the demoralization of spirits due to the failures of previous investigators. Those who have labored for years without gaining any satisfactory light on the subject may easily convince themselves that there are no definite laws

of celestial development; or imagine that such laws as exist are the outgrowth of various processes,—under repulsive and even explosive forces, as well as under the more familiar attractive force of gravitation. The investigator who has repeatedly failed will readily persuade himself that nature has few, if any, simple laws. This mistaken tendency of many minds is supported and confirmed by the diversity of process apparently required to harmonize discordant phenomena; and the love of novelty thus suggested is often stronger than the love of truth.

Accordingly we have a multitude of theories, most of which have no foundation whatever, and should never have been advanced. The promulgation of theories wholly devoid of foundation is injurious to science and simply aids in the propagation of error. When nothing is known, however, almost any hypothesis which unites and harmonizes phenomena is philosophically justifiable, and may be of some value for the time being; but when means exist for confronting hypotheses with observations, so as to establish contradictions with known phenomena, it is idle and vain to consider any hypothesis which is not free from contradiction.

Heretofore most of the theories of cosmical evolution proposed have been involved in some inconsistency. Indeed, most of them have been directly contradicted by the most obvious phenomena, which admit of no dispute; and yet many of these baseless speculations have continued to circulate even in publications of supposed scientific standing. The vague theories put forth by persons of obscure mind only serve to muddy the stream, so that no one can penetrate beneath the surface; and this leads a considerable body of observers to concentrate attention chiefly on superficial phenomena, which have the double fascination of apparent obviousness and at the same time may be grasped without much labor. But sagacious investigators are not taken in by such palpable deceptions. They are accustomed to look beneath the surface, and realize fully that hard work, extending over many years, is the price which must be paid for discoveries of real value. Until results can be obtained which admit of no contradiction they prefer to wait for more light, and thus have been able to make

but few positive advances in cosmogony. In the present discussion we shall refer especially to the solar system, but the principles are obviously applicable to all systems in space, and we need not dwell on the universal character of the theory.

The roundness of the orbits of the planets and satellites has been remarked with wonder and admiration from the earliest ages of science. This remarkable geometrical property of the planetary paths excited the speculative curiosity of ARISTARCHUS and ARCHIMEDES, HIPPARCHUS and PTOLEMY, KEPLER and NEWTON; but while all geometers followed the Greeks in admiring nature's apparent preference for the circle, no one of them attempted to explain this tendency till LAPLACE promulgated the nebular hypothesis in 1796, and accounted for the circularity of the orbits by a rotation of the central mass under gradual acceleration, which would detach the attendant bodies quite gently and set them revolving in orbits approximately circular. LAPLACE's explanation has been generally accepted, and for more than a century it has been universally assumed that the planets and satellites were originally detached from the central bodies which now govern their motions.

Yet as long ago as 1861 BABINET had proposed a mathematical criterion for testing the Laplacian theory, and on applying it to our system found that the classic nebular hypothesis was not confirmed. This criterion rests on the mechanical principle of the conservation of areas, according to which the moment of momentum of a rotating mass is unchanged whatever be the change in radius. Thus if ω be the angular velocity of rotation of a globe of radius r , ω' and r' the corresponding quantities at another epoch; then it follows that

$$r^2\omega = r'^2\omega'$$

On applying this formula to our actual system, with the numerical data adopted in *Astronomische Nachrichten* No. 3992, we find the results given in the accompanying table.

BABINET had applied his criterion to the case of the Earth and *Neptune* and found that the rotation of the hypothetical solar nebula when it was expanded to fill these orbits would not be rapid enough to detach these planets. As his criticism

of LAPLACE's theory was destructive and not constructive, it shared the fate common to efforts of this kind, and has been generally lost sight of. Consequently the effect of BABINET's test on current speculative thought was insignificant. The above table gives the best available data for all parts of the solar system, and shows that none of the planets and satellites were ever detached from the central masses which now govern their motions.

Thus we see that the premise underlying LAPLACE's hypothesis, implying that the attendant bodies were detached by rotation, was false, and consequently the reasoning based thereon quite unjustifiable. Therefore his venerable explanation of the roundness of the planetary orbits falls to the ground, and another cause must be sought which admits of verification by means of criteria of acknowledged mathematical rigor.¹

TABLE SHOWING THE APPLICATION OF BABINET'S CRITERION
TO THE PLANETS AND SATELLITES, WHEN THE SUN AND
PLANETS ARE EXPANDED TO FILL THE ORBITS OF
THE BODIES REVOLVING ABOUT THEM.

Solar System.	Planet.	R ₀ The Sun's Observed Time of Rev.	P ₀ Observed Period of Planet.	R _c Time of the Sun's Rotation Calculated by BABINET'S Criterion.
	<i>Mercury</i>	25.3 days = 0.06267 yrs.	0.24085 years	479 years
	<i>Venus</i>		0.61237 "	1673 "
	The Earth		1.00000 "	3192 "
	<i>Mars</i>		1.88085 "	7424 "
	<i>Ceres</i>		4.60345 "	24487 "
	<i>Jupiter</i>		11.86 "	86560 "
	<i>Saturn</i>		29.46 "	290962 "
	<i>Uranus</i>		84.02 "	1176765 "
	<i>Neptune</i>		164.78 "	2888533 "

¹ The discussion from here on is substantially identical with that embodied in an article communicated to the *Astronomische Nachrichten* under date of January 1, 1909.

Sub-Systems.	Satellite.	R_o Adopted Rotation of Planet.	P_o Observed Period of Satellite.	R_c Time of Planet's Rotation Calculated by BABINET'S Criterion.
Earth	The Moon	1 day	27.32166 days	3632.45 days
Mars	Phobos	24.62297 hrs.	7.6542 hrs.	190.62 hrs.
	Deimos		30.2983 "	1193.52 "
Jupiter	V	9.928 "	11.9563 "	64.456 "
	I		1.7698605 days	14.60 days
	II		3.5540942 "	36.900 "
	III		7.1663872 "	93.933 "
	IV		16.7535524 "	290.63 "
	VI		250.618 "	10768.8 "
	VII		265.0 "	11602.4 "
	VIII		930.73 "	61997.2 "
Saturn	Inner Edge of Ring	10.641 hrs.	0.236 day	0.6228 day
	Outer Edge of Ring		0.6456 "	2.383 days
	Mimas		0.94242 "	4.2902 "
	Enceladus		1.37022 days	7.0615 "
	Tethys		1.887796 "	10.822 "
	Dione		2.736913 "	17.751 "
	Rhea		4.517500 "	34.620 "
	Titan		15.945417 "	186.05 "
	Hyperion		21.277396 "	273.06 "
	Japetus		79.329375 "	1580.1 "
	Phæbe		546.5 "	20712. "
Uranus	Ariel	10.1112 hrs. (cf. <i>A. N.</i> 3992)	2.520383 "	33.714 "
	Umbriel		4.144181 "	65.435 "
	Titania		8.705897 "	176.05 "
	Oberon		13.463269 "	314.83 "
Neptune	Satellite	12.84817 hrs. (cf. <i>A. N.</i> 3992)	5.87690 "	141.8 "

Now the planets and satellites could be formed in but one of two possible ways: (1) They might conceivably have been detached from the central masses which now govern their motions, by acceleration of rotation, as supposed by LAPLACE. (2) They might have been original nuclei captured in the midst of the solar nebula, and afterwards gradually built up by the agglomeration of more cosmical dust, while at the same time the orbital motion in this resisting medium would have

reduced the major axes and eccentricities of their orbits and thus produced the near approach to perfect circularity now observed in our solar system.

We have, however, just proved, by the application of BABINET'S criterion, based on the law of areas, that these bodies could not have been detached from the central masses about which they now revolve. *Accordingly it follows that they were all captured, and have since had their orbits reduced in size and rounded up under the secular action of the resisting medium formerly pervading the planetary system.*

From this unexpected conclusion there is absolutely no escape; for we may prove this by the following reasoning. The effect of a resisting medium in reducing the major axis and eccentricity of the orbit of the resisted body is fully recognized, and has been known for more than a hundred years. The formulæ for the changes of these two important elements may be reduced to the form

$$\delta a = -\frac{2a^2}{p^2(1+m)} [A'v + \text{periodic terms}] \dots (3)$$

$$\delta e = -\frac{2}{p} [Aev + \text{periodic terms}] \dots \dots \dots (4)$$

where p is the parameter of the orbit, a the semi axis major, e the eccentricity, v the true anomaly, and m the mass of the resisted planet, and A and A' constants. As both of these expressions are negative, it follows that under the secular action of a resisting medium the major axis and eccentricity always decrease. In deriving these formulæ, however, the density of the resisting medium is supposed to increase towards the center, conformable to what is observed in the nebulæ and shown to result from the theory of gases.

LAPLACE himself has discussed this question with characteristic penetration in the *Mécanique Céleste* (Liv. X, ch. VII, § 19). He shows that when the density of the medium, represented by $\Phi \left(\frac{1}{r}\right)$ increases towards the Sun, the semi axis major and eccentricity always decrease; and finally remarks: "Therefore at the same time that the planet approaches towards the Sun, by the effect of the resistance of the medium,

the orbit will become more circular." It is surprising that it did not occur to the author of the *Mécanique Céleste* that the roundness of the orbits of the planets and satellites could be explained by a resisting medium quite as easily and simply as by the theory of a rotation which would gently detach these masses and set them revolving in orbits which are nearly circular, especially since the nebular hypothesis itself necessarily implies the existence of such a medium where the planets and satellites now revolve.. LAPLACE merely remarks that if the nebula filled the whole of this space the bodies would encounter such resistance as to cause them to fall into the Sun; *but in making this statement he overlooked the fact that most of the nebulous matter did go into the Sun and planets, and it is from this circumstance that the central masses became so preponderant, while the attendant bodies are in all cases so very small.*

During a recent conference with my friend Professor GEORGE DAVIDSON, I mentioned LAPLACE'S proof that a resisting medium had formerly acted against *Jupiter's* satellites I, II, III, to bring about a near approach to commensurability in their mean motions, and thus enable their mutual attraction to establish a rigorous relationship under the influence of this slowly acting cause. This venerable astronomer justly remarked: "LAPLACE had the true cause in sight, but he did not carry it far enough to discover the actual process by which the solar system was formed."

Evidently LAPLACE had not tested his nebular hypothesis by the criterion based on the conservation of areas, afterwards proposed by BABINET, and it simply did not occur to him that the circularity of the orbits pointed unmistakably to the secular action of a resisting medium. As the very existence of a nebula implies resistance to bodies revolving within it, this oversight is the more remarkable; and unfortunately not only was LAPLACE'S reasoning vitiated, but an equally disastrous effect exerted on all other investigations in cosmical evolution for more than a century, because all mathematicians followed the same line of thought, on the false premise that the planets and satellites were detached from the central bodies which now govern their motions.

If in the light of this new theory of the shaping of the orbits under the secular effects of resistance we examine our solar system carefully we shall find many phenomena confirming the former existence of such a medium in our system.

It must suffice here to call attention to but a very few of the numerous survivals of the primordial resisting medium still shown by our system:—

(1) The rapid motion of *Phobos*, the inner satellite of *Mars*, which has been brought down near the planet by resistance, till it now revolves in less than a third of the time of the planet's rotation. It is true that Professor Sir G. H. DARWIN explains this motion of *Phobos* by a tidal retardation of the axial rotation of *Mars*, but in view of the large part undeniably played by the resisting medium in the formation of our system as a whole this explanation will not hold, though a very small part of the observed effect may be traceable to tidal friction.

(2) The famous inequality in the motions of the three inner Galilean satellites of *Jupiter*, which point unmistakably to a resisting medium, as was sagaciously pointed out by LAPLACE in 1796. His remarks on this subject are as valid and convincing as any which could be made to-day.

(3) The observed rapid motion of the inner ring of *Saturn*, which greatly exceeds the axial rotation of the planet. The rings evidently were never detached from the planet, but simply survive out of a much larger mass of cosmical dust which has been absorbed in building up the mass of *Saturn*. All the data in the table relative to BABINET'S criterion bear on this same question.

(4) The general fact that the satellite orbits are so round, and in general rounder and rounder the nearer we approach the planets, confirms the capture of these bodies in a medium which was denser towards these centers. The roundness of the satellite orbits shows that resistance was very effective from *Mars* to *Neptune*, and therefore no doubt throughout our whole solar system.

(5) The retrograde motion of *Saturn's* satellite *Phæbe* and *Jupiter's* eighth satellite is likewise to be explained by the capture of these bodies. Whatever may have been their orig-

inal eccentricities at the time of capture, even retrograde directed bodies could have survived, because the medium against which they revolved was of very slight density at that great distance from the planets. This slight density of the resisting medium at this distance is also indicated by the survival of considerable eccentricities in the orbits of these two satellites. The eccentricity of the orbit of *Phæbe* is given as 0.22, that of *Jupiter VIII* as 0.44, which are certainly anomalous enough to excite our suspicion. It is not by chance that retrograde motion in these two cases is associated with the highest eccentricities observed among all the satellites thus far discovered.

(6) The orbits of the asteroids have been gathered into their present positions mainly by the action of *Jupiter* and of the resisting medium. Originally they were more widely distributed over the whole system than at present; but even now they overlap the orbits of *Jupiter* and *Mars*, and there may be others of still wider range.

(7) The extreme roundness of the orbit of *Neptune* is a clear indication that this planet moved for a long time against a vast amount of nebulous resistance. Therefore it is very improbable that our planetary system terminates with *Neptune*. *In all probability there are several more planets beyond the present boundary of the system, some of which may yet be discovered.*

(8) The equatorial accelerations noticed on the globes of the Sun and of *Jupiter* and *Saturn* are to be explained by the falling in of matter revolving in vortices about these bodies. As the orbital motion of this matter near these bodies exceeds that depending on the axial rotation, the falling particles necessarily produce an equatorial acceleration. This process may still be going on; at any rate, it has been in progress so recently that the effects still continue.

(9) The solar system was formed from a spiral nebula, revolving and slowly coiling up under mechanical conditions which were essentially free from hydrostatic pressure. And spiral nebulae themselves arise from the meeting of two or more streams of cosmical dust. The whole system of particles has a sensible moment of momentum about some axis, and

thus it begins to whirl about a central point, and gives rise to a vortex. In the actual universe the spiral nebulae are to be counted by the hundreds of thousands, if not by the million, and it is evident that they all arise from the automatic winding up of streams of cosmical dust, under the attraction of their mutual gravitation. The two opposite branches of the spiral nebulae, so often shown on photographs, represent the original streams of cosmical dust which are coiling up and forming gigantic spiral systems.

(10) When the nebula rotates and the coils wind up in such a way as to leave open spaces between the coils, or at least freedom from sensible hydrostatic pressure, the usual result is the development of a system made up of small bodies, such as the planets compared to the greatly preponderant Sun, or the satellites compared to the much greater planetary masses which control their motions. In the solar system where the conditions are accurately known this is proved to have occurred; and it was repeated so many times, always with uniform results, giving a large central mass and small attendant bodies, that the general law for this condition is clearly established.

(11) If the streams so converge that the nebulous mass becomes very concentrated at the center, so as to become a figure of equilibrium under the pressure and attraction of its parts, the nebula may divide into a double star, as I have elsewhere inferred from the researches of POINCARÉ and DARWIN on the figures of equilibrium of rotating masses of fluid.

(12) Now both of these forms of development, depending on variations of the two processes, are abundant in the actual universe, and probably almost all of the apparently single stars are surrounded by systems of planets. At least one fifth of all the stars are estimated to be double or multiple. If we assume the chances of the two forms of development to be equal we may calculate from the preponderance of small bodies actually found in the solar system—eight principal planets, twenty-five satellites (besides our Moon), and 625 asteroids—that the chances of a nebula devoid of hydrostatic pressure producing small bodies is about 2^{658} to 1, or a decillion decillion (10^{66}) to

the sixth power, to unity. This figure is so very large that we shall content ourselves with illustrating a decillion decillion, and for this purpose we avail ourselves of a method employed by ARCHIMEDES to illustrate his system of enumeration. Imagine sand so fine that 10,000 grains will be contained in the space occupied by a poppy seed, itself about the size of a pin's head; and then conceive a sphere described about our Sun with a radius of 200,000 astronomical units (*a Centauri* being at a distance of 275,000), entirely filled with this fine sand. The number of grains of sand in this sphere of the fixed stars would be a decillion decillion (10^{66}). All these grains of sand against one is the probability that a nebula devoid of hydrostatic pressure such as that which formed the planets and satellites will lead to the genesis of such small bodies revolving about a greatly predominant central mass.

This is a very brief and inadequate outline of a few of the leading points in a very large investigation with which I have been occupied. Most of these results were established over six months ago, and I have had opportunity to discuss them with several experienced astronomers. It is hoped that the whole investigation may appear as Volume II of my "Researches on the Evolution of the Stellar Systems"; but it seemed advisable to communicate this brief summary of some of the most interesting points without further delay.

The effect of this work will be to give the theory of the resisting medium the highest importance in all researches relating to the history of the universe. It is very remarkable that the principal secular effects of this cause are exactly opposite to those due to tidal friction as investigated by DARWIN. For while tidal friction usually increases the major axis and eccentricity of an orbit, the resisting medium as regularly decreases both of these elements. In the actual physical universe both causes are at work together, sometimes one influence predominating and then the other. Resisting medium is relatively most effective in a system made up of a large central sun, and small attendant bodies such as the planets of our solar system, and in the systems of satellites dominated by large planets. Tidal friction is most effective in systems made up of two large masses, such as the double stars.

It has seemed important to call attention to the cause of the roundness of the orbits of the planets and satellites, because it appears likely that the criteria now introduced may go far toward clearing up the mystery which has always surrounded the origin of the solar system.

In all the celebrated speculations of the distinguished astronomers who have occupied themselves with the genesis of our solar system, four phenomena have ever been foremost: (1) The great circularity of the orbits; (2) The small inclinations and the common direction of the orbital motion; (3) The smallness of the attendant planets and satellites compared to the large central masses which govern their motions; (4) The regularity and order everywhere found in our system, the distances, masses, and mutual relations of the orbits being such as to secure maximum stability and perpetuity. All these phenomena and many others are now perfectly explained by a simple theory, which also conforms to the laws of spiral development observed in the sidereal universe. A simple and obvious theory which accounts for the known phenomena while all other theories are involved in contradiction, will naturally have a strong claim to acceptance. Indeed we cannot refuse our assent to it without violating the recognized rules of natural philosophy as formulated by NEWTON in the *Principia*.

U. S. NAVAL OBSERVATORY,
MARE ISLAND, CAL., January 30, 1909.

PHOTOGRAPHS OF COMET *c* 1908 (MOREHOUSE)

BY A. ESTELLE GLANCY.

From September 19th until December 15th, at which latter date the comet could be followed only long enough to photograph the head, exposures have been made at the Lick Observatory on every favorable occasion. Successful exposures were made on twenty-eight nights. The nights omitted were unfavorable,¹ by reason of too strong moonlight, clouded sky, or

¹ The number of unfavorable nights was unusually large this year.